Hurricane Katrina Flooding and Oil Slicks Mapped with Satellite Imagery

By Russell Rykhus and Zhong Lu

A multiple-database approach that combined remotely sensed data from Radarsat-1 and Landsat Thematic Mapper Plus (ETM+) imagery was used to map Hurricane Katrina-induced flooding and to identify offshore oil slicks. Maps depicting the areal extent of flooding, oil slicks, and floating debris provide vital information to emergency managers for directing flood-relief efforts and the clean-up of polluted waters.

Background

With wind speeds of approximately 145 mi/hour (233 km/hour), a storm surge of 27.9 ft (8.5 m), and heavy rains, Katrina made landfall near Buras, La., on August 29, 2005, as a category 3 hurricane. Katrina pounded the U.S. Gulf Coast States of Alabama, Louisiana, and Mississippi with life-threatening floods and destruction. Katrina's high winds and high storm surge combined to breach the levees protecting New Orleans, La., a city located below sea level, and flooded approximately 80 percent of the city. Katrina also caused major damage to the region's oil and natural gas production and refining capabilities. On September 2, 2005, the Associated Press reported that Katrina had damaged 58 oil platforms, 30 of which were reported "lost," while 1 platform had been blown nearly 62 mi (100 km) from its original location.

Synthetic Aperture Radar (SAR) data obtained by the Radarsat-1 satellite and optical data obtained by the Landsat ETM+ are complementary in nature. The all-weather microwave SAR data are able to penetrate cloud cover and a vegetation canopy to derive information on surface structure and dielectric constant, and the optical Landsat ETM+ data contain spectral information relating to vegetation health (Wang, 1995; Oberstadler, 1997; Henderson and others, 1998). Combining the SAR and Landsat ETM+ imagery enables the accurate depiction of flooding and the possible identification of oil slicks and debris flows on calm water. A multiple-database approach using a preflood Landsat ETM+ image mosaic and

Radarsat-1 SAR images acquired during the flood were used to map the flooding in New Orleans and its vicinity.

Methods

Unlike optical sensors, which record sunlight reflected from Earth's surface, the SAR backscatter signal is controlled by environmental factors such as terrain slope, surface roughness, and moisture content of surface materials. In calm weather, water acts as a specular reflector (or forward scatterer) of the SAR signal, resulting in very low backscatter values for flooded areas (fig. 1). By using prior knowledge of how the SAR backscatter signal responds to the vegetation information that is provided by the Landsat ETM+ data, areas having an unusually low SAR backscatter return can be used to accurately detect and map flood extent in open areas and in relatively short vegetation (Oberstadler, 1997; Henderson and others, 1998; Wang, 2002). A "double-bounce" radar interaction can be used to map flooding in forests and in urban areas (fig. 1). With the double-bounce interaction, all of the SAR signal is reflected away from the sensor by the water surface, toward a tree or building, and is then reflected directly back to the sensor. The double-bounce interaction thus produces a very high backscatter return. If an area is not flooded, the primary type of radar interaction is "volume scattering," which produces a moderate backscatter return (fig. 1).

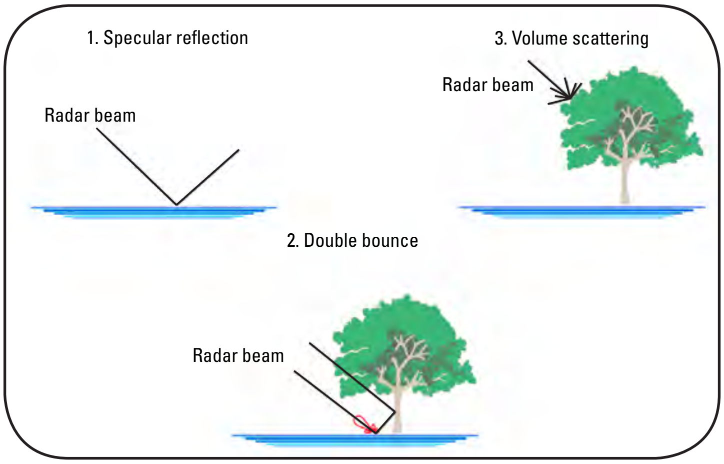

Figure 1. Illustration showing the three types of radar interactions. (1) Specular reflection occurs when the radar beam makes contact with a smooth body of water. The radar beam is specularly reflected, or reflected forward away from the radar sensor, resulting in low backscatter values. (2) The double-bounce interaction typically occurs in flooded forests. With a double-bounce interaction the radar beam travels through the open canopy (with respect to the wavelength of the radar) and makes contact with the tree trunk. After striking the trunk, the signal is reflected downwards toward the water's surface and is then specularly reflected towards the radar sensor, resulting in high backscatter values. (3) In volume scattering, the radar signal, upon making contact with the vegetation canopy, is randomly scattered in all directions, resulting in moderate backscatter values.

The first step in mapping flood extent was to classify the Landsat ETM+ image into three basic categories according to the greenness of an area: (1) marsh vegetation (moderately low greenness), (2) forested (high greenness), and (3) urban areas. Classifying flooding in lowland vegetation (specular reflection), flooding in tall vegetation (double-bounce interaction), and flooding of urban areas (also double bounce) was accomplished by establishing thresholds in both the Radarsat-1 data and the Landsat ETM+ data. To classify flooding of lowland marsh vegetation the area must meet the criteria that both the preflood Landsat ETM+ data need to have a low to moderately bright greenness value and have a very low radar backscatter return indicating a specular type of interaction. Areas classified as flooded forest need to be very green in the Landsat ETM+ image and have a very bright radar backscatter return. The classification of urban flooding is first restricted to areas that were classified as "urban" by the Landsat ETM+ imagery and is further restricted to areas having a backscatter return several decibels (dB, 10 times the common logarithm of intensity of radar return) higher than the return for an unflooded urban area.

Oil slicks on open water tend to dampen the roughness of the water and to change the texture of the SAR backscatter return. This change allows for the discrimination of oil slicks on open water, provided that light to moderate wind conditions exist (Henderson and others, 1998; Rykhus and others, 2005). The weather reporting station for New Orleans was inoperable during the first Radarsat-1 acquisition (September 2, 2005), but stations in Baton Rouge, La., and Lafayette, La., reported light winds out of the northeast and east-northeast directions, respectively. On September 5, 2005, the New Orleans (by then operational), Baton Rouge, and Lafayette weather stations also reported light winds. The presence of light winds over the study area during the acquisition of the Radarsat-1 data allowed us to identify oil slicks in the imagery.

Because abrupt changes in the SAR backscatter value and changes in texture both indicate the presence of an oil slick, we decided to run a texture algorithm on both Radarsat-1 scenes to highlight areas with small changes in texture. Areas of open water with very low backscatter returns and with a very smooth texture were classified as an oil slick (Solberg and others, 1999; Mercier and others, 2006). Our oil slick classification algorithm was designed to eliminate sheltered coastal areas and very small areas; however, because other natural phenomena (schools of certain fish species, rain cells, and certain types of decaying vegetation) can appear similar to a petroleum-based oil slick, our classification should be considered as preliminary until confirmed by other sources.

Analysis and Discussion

By using Radarsat-1 C-band (wavelength of 2.4 inches (5.7 cm)) SAR images acquired on September 2 and September 5, 2005, preliminary inundation maps (figs. 2 and 3) were derived to show the extent of flooding caused by Katrina. By combining the flood extent derived from the SAR images with preflood digital elevation data derived from light detection and ranging (lidar), flood volumes for New Orleans and its immediate vicinity were calculated to be approximately 690,000,000 yd^3 (~528,000,000 m^3) on September 2, 2005, and 676,000,000 yd^3 (~517,000,000 m^3) on September 5, 2005. These flood-volume estimates for the New Orleans urban area are in close agreement with those provided by Gesch (2005) (*http://gisdata.usgs.net/hazards/katrina/science.php*), whose estimate is based on a digital elevation model (DEM). While Gesch (2005) and others concentrated their efforts on flooding within the city of New Orleans, the larger extent of the Radarsat-1 scenes shows that large areas of coastal Louisiana also suffered severe flooding.

In addition, the sensitivity of the SAR data to the presence of oil on the surface of open waters provides the opportunity to identify potential oil slicks in both the September 2 and September 5, 2005, images (figs. 2 and 3). Some oil slicks appear to be related to offshore oil platforms that appear as bright specks in many radar images; however, other slicks do not have obvious sources of origin. A possible source for some of the oil slicks may be spills from large onshore oil refineries and storage facilities. One oil spill in Chalmette, La., a town located a few miles southeast of New Orleans, was not detected until September 7, 2005. In Chalmette, a ruptured oil tank is estimated to have spilled some 10,000 barrels of oil (MSNBC, September 7, 2005 (*http://msnbc.msn.com/id/9175553*)). Because of the narrow confines of the Mississippi River and the wind-sheltering effects provided by the levees, we were unable to map possible oil slicks on the river. These oil spills as mapped should be treated as a preliminary estimate until confirmed by other sources of data.

Our analysis also reveals that two rather large debris flows in the Gulf of Mexico and an influx of contaminated water (sewage and other household chemicals and oils) into Lake Pontchartrain were identified in the September 5, 2005, image (fig. 3). The plume of contaminated water in Lake Pontchartrain (fig. 3) appears to be linked to the pumping of contaminated New Orleans flood waters. The contaminated plume can be traced to the first operational pumping station, which started only several hours before the acquisition of the September 5, 2005, Radarsat-1 acquisition.

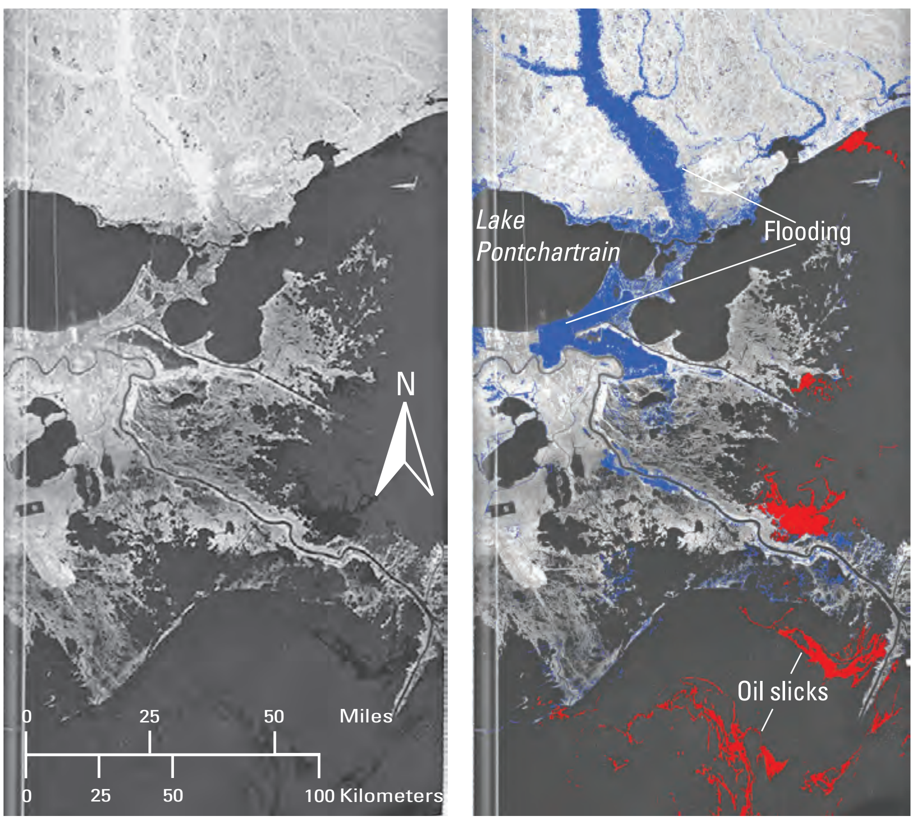

Figure 2. The Radarsat-1 Synthetic Aperture Radar (SAR) image and the extent of flooding caused by Hurricane Katrina (shown in blue) and several possible oil slicks (shown in red) were mapped by combining the September 2, 2005, Radarsat-1 SAR imagery with a preflood Landsat Thematic Mapper Plus (ETM+) image mosaic. Since oil slicks can have a signature similar to that produced by other natural phenomena, these mapped oil slicks should be treated as a preliminary estimate until confirmed by other data sources.

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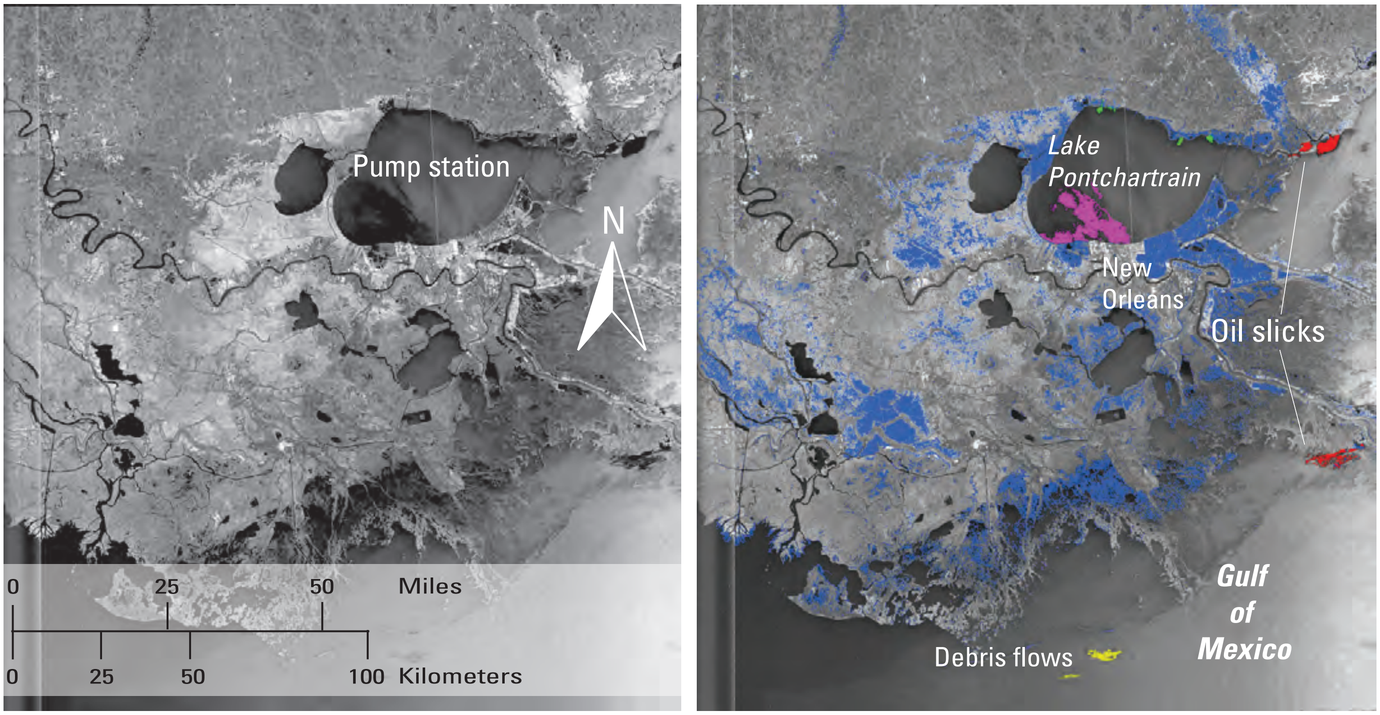

Figure 3. Covering a larger extent than the image acquired on September 2, 2005, the Radarsat-1 image acquired on September 5, 2005, was used to define the extent of flooding caused by Hurricane Katrina (shown in blue), two oil slicks (shown in red), a debris flow (shown in yellow), and a large plume of oil contaminated water (shown in purple) being pumped into Lake Pontchartrain, La.

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